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The Impact of Stellar Feedback on Formation of Young Massive Clusters via Fast HI Gas

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Young massive clusters (YMCs) are exceptionally dense stellar systems, with densities exceeding $10^3\ \mathrm{M}_\odot\ \mathrm{pc}^{-3}$ [1]. While YMCs are as dense as globular clusters, they are as young as open clusters in the Milky Way, suggesting they might be precursors of globular clusters [2]. Recent observations by the James Webb Space Telescope (JWST) suggest that early galaxies at redshifts of approximately $z \sim 4-10$ form at least 10% to 30% of their stars within YMCs [e.g., 3]. This demonstrates that understanding YMC formation is crucial for elucidating the star formation history of galaxies.

In the Large Magellanic Cloud (LMC), [4] and [5] performed detailed analyses of neutral atomic hydrogen (HI) gas using observational data from the Australia Telescope Compacta Array and Parkes HI gas surveys. They found characteristic structures indicative of HI gas collisions in the gas-surrounding regions where YMCs form. The colliding velocity is estimated to be ~100 km/s, consistent with the velocity of gas collisions resulting from the galactic interaction with the Small Magellanic Cloud. These findings suggest that fast HI gas collisions could potentially trigger the formation of YMCs in the LMC, implying that YMC formation via gas collisions can be important in interacting galaxies in general.

In this study, we examine the formation of YMC forming clumps via fast HI gas collisions (100 km/s) and their subsequent evolution into YMCs by using three dimensional magnetohydrodynamics simulations involving self-gravity, feedback, and detailed thermal/chemical processes [see also, 6]. We considered photoionization feedback in an approximate fashion by elevating the gas temperature within the Strömgren radius to ~10^4 K.

By a series of simulations (Figure 1), we find that even in the presence of photoionization feedback, massive (~$10^5\ \mathrm{M}_\odot$) and compact (~ pc) gas clumps can be produced through HI gas (1 /cc) collisions with fast velocity v = 100 km/s. The resulting clumps are sufficiently compact, with escape velocities surpassing the sound speed of the HII region, indicating tight gravitational binding. Consequently, these circumstances promote efficient star formation within the massive gas clumps, ultimately leading to their evolution into young massive clusters (YMCs). Conversely, when massive stars emerge within low-mass clumps, feedback effects induce clump evaporation.

We also found that fast collisions (100 km/s) allow the formation of exceptionally massive gas clumps exceeding $10^6\ \mathrm{M}_\odot$ when considering dense gas inflows (10 /cc). This is consistent with the observational fact that regions experiencing higher ram pressure collisions are conducive to the formation of more massive star clusters.

In cases of low-velocity (15 km/s) gas collisions, such as those induced by supernova shocks, the formation of molecular gas within the shocked layer is inefficient, especially at colliding gas density as low as 1 /cc. This is because the sheet formed by weak collisions has a low density and takes a long time to form molecular gas, resulting in failed star formation. Even in low-velocity collisions, if denser gas (10 /cc) collide, massive gas clumps can form as long as the compression continues >10 Myr. However, achieving such prolonged compression by supernova-induced shocks within a galaxy hardly happens, indicating the preference for large-scale gas collisions arising from galactic interactions.

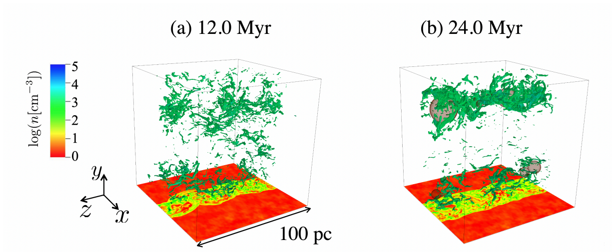

Figure 1: Snapshots of the three-dimensional structure of high-density gas $n > 10^3$ /cc at two distinct epochs, (a) $t = 12.0$ and (b) $t = 24.0$ Myr. The red spheres in the box illustrate formed HII regions. The bottom panels display two-dimensional density cross-sections on the $x-z$ plane at $y = 0$.

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